SLIDING MODE FLUX OBSERVER OF INDUCTION MOTOR

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Summary This paper deals with the sliding mode theory for direct torque and flux controlled (DTFC) induction motor drive. The aim of this paper is implementation of sliding mode theory for design of robust sensorless control of the drive with DTFC. This contribution describes proposed control and flux observer as well as presents simulation results and experimental evidence of the laboratory prototype of the drive.

1. INTRODUCTION

The sensorless control of induction machine is explored and discussed in the literature for very long time. There were published several interesting papers and books covering this issue – e.g. [1], [2]. However, this problem is still open. Especially sensorless operation of the drive in standstill and in low speeds is not satisfactorily resolved. One of the possible solutions making possible operation of the drive near zero speed is the application of the sliding mode theory. This contribution is the follow-up to the papers [3], [4]. The aim of this contribution is implementation of sliding mode theory for design of robust sensorless control of the drive with DTFC. This contribution describes proposed drive control and flux observer as well as presents simulation results and experimental evidence of the laboratory prototype of the drive.

2. THEORY

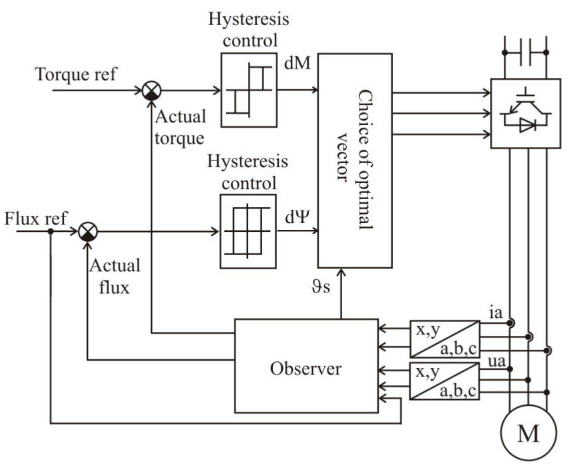

Fig. 1. Proposed control scheme with the included closed-loop observer

The stator flux and torque are controlled by hysteresis controllers. The outputs of the flux and torque controllers are the inputs to the block "choice of optimal vector". Here, depending on the demand for the change in the torque and stator flux and the information about the actual position of the stator flux computed in observer, the optimal voltage vector is chosen from the table. The motor stator flux controller is designed to achieve a real sliding-mode motion on the manifold $\sigma_s = 0$ and at the same time, provide a first order transient toward sliding surface.

$$u_s^d(k) = u_s^d(k-1) + \frac{Krs}{Ts}((I + TsD)\sigma_s(k) - \sigma_s(k-1)), \tag{1}$$

where

$$\sigma_S = \psi_s^d - \hat{\psi}_S^S . \tag{2}$$

The proposed control system is only slightly dependent on the system parameters changes.

3. SIMULATION RESULTS

The simulations of the laboratory prototype of the induction machine drive of rated power of 1.5kW have been realized in Matlab. The following figures describe the behavior of proposed control and observer under both steady-state (Fig. 2) and transient (Fig. 3, Fig. 4) conditions. Fig. 2 compares the components of the rotor flux vector in stationary reference frame ($\Psi_{r\alpha}$, $\Psi_{r\beta}$) obtained from proposed observer with the components of the rotor flux vector computed by the “ideal” mathematical model of the machine. Fig. 3 presents the response of the drive on the step change of the load torque. Fig. 4 illustrates behavior of designed speed control loop.

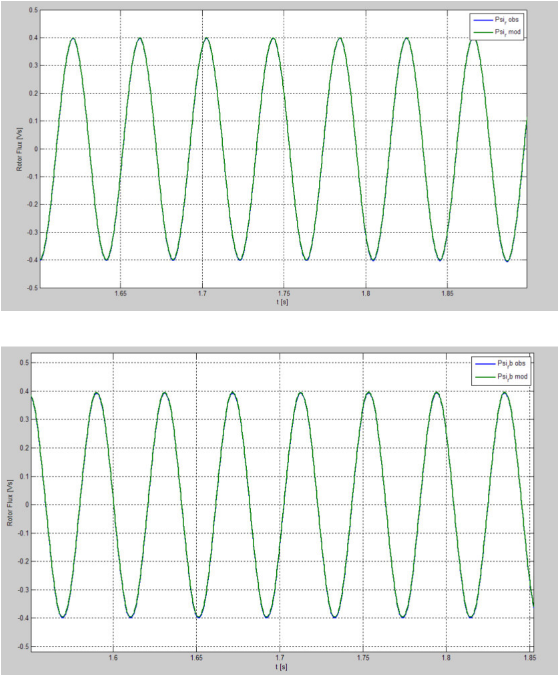

Fig. 2. Comparison of components of rotor flux vector in stationary reference frame ($\Psi_{r\alpha}$, $\Psi_{r\beta}$) estimated by proposed observer with components of rotor flux vector computed by the "ideal" mathematical model of machine: electrical rotor speed of 20 Hz, load torque of 1 Nm

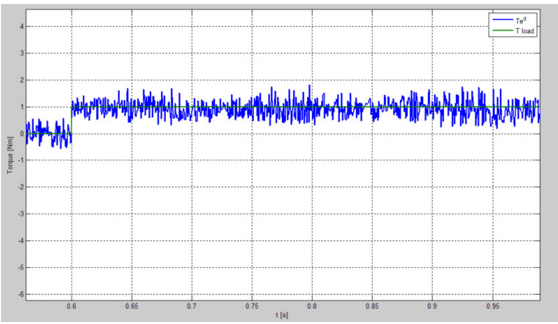

Fig. 3. Step change of the load torque $T_L = 0 \rightarrow 1$Nm, electrical rotor speed of 20Hz

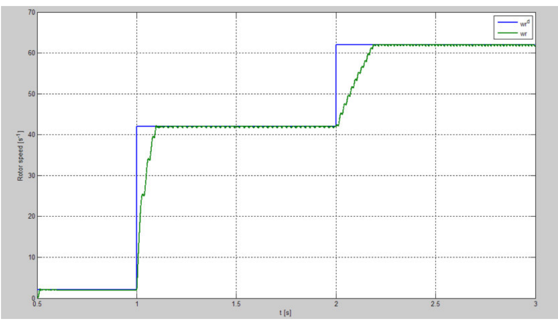

Fig. 4. Behaviour of speed control loop: Speed command 0Hz (t = 0,5s) $\rightarrow$ 2Hz (t = 1s) $\rightarrow$ 42Hz (t = 2s) $\rightarrow$ 62Hz

4. EXPERIMENTAL RESULTS

The proposed control including flux observer have been implemented in dSpace rapid prototyping card (DS1103 PPC Controller Board) (Fig. 5). The configuration of designed laboratory prototype is shown in the Fig. 5. The drive consists of induction machine of rated power of 1.5kW, which is loaded using mechanically coupled PMSM servo drive. The induction machine is fed by frequency converter Danfoss VLT5004, which is controlled by above described dSpace system.

The following figures present selected experimental results. Fig. 7 illustrates behaviour of designed speed control loop. Fig. 8 depicts the stator phase currents (the deformation of the current waveforms is caused by low sampling rate). Fig. 9 shows the components of stator current vector in stationary reference frame ($i_{s\alpha}$, $i_{s\beta}$).

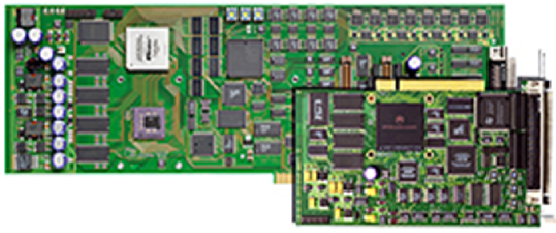

Fig. 5. Employed dSpace System (DS1103 PPC Controller Board)

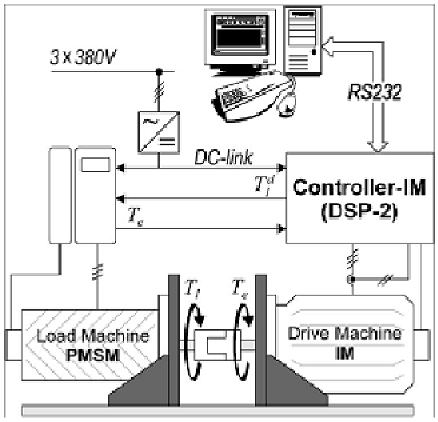

Fig. 6. Configuration of laboratory prototype of drive

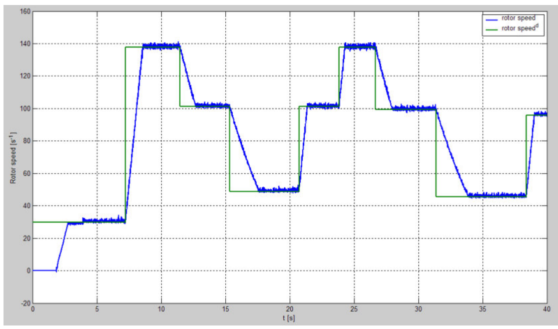

Fig. 7. Propriety of speed control loop (speed ramp of 80Hz/s)

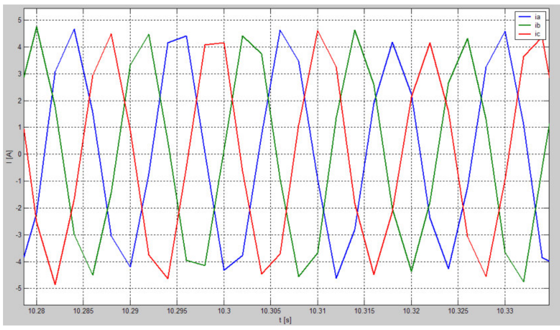

Fig. 8. Stator phase currents (low sampling rate): Ψ_s=0,4Wb, load torque of 1Nm, el. rotor speed of 50Hz

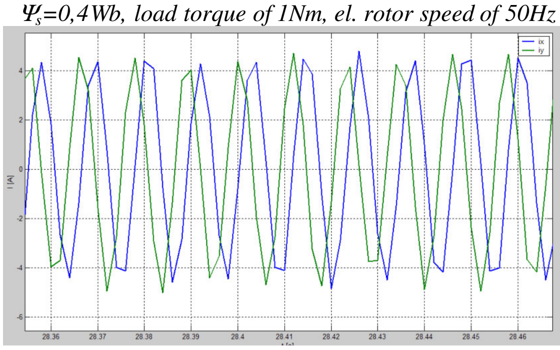

Fig. 9. Components of stator current vector in stationary reference frame ($i_{s\alpha}$, $i_{s\beta}$)

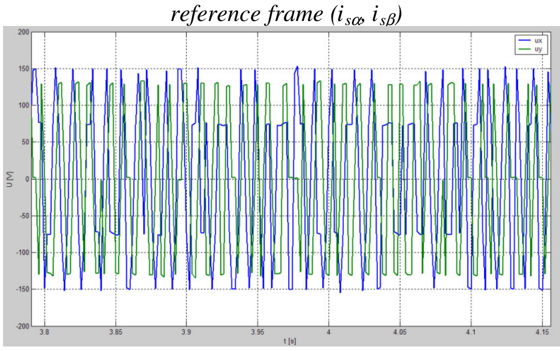

Fig. 10. Components of stator voltage vector in stationary reference frame ($u_{s\alpha}$, $u_{s\beta}$)

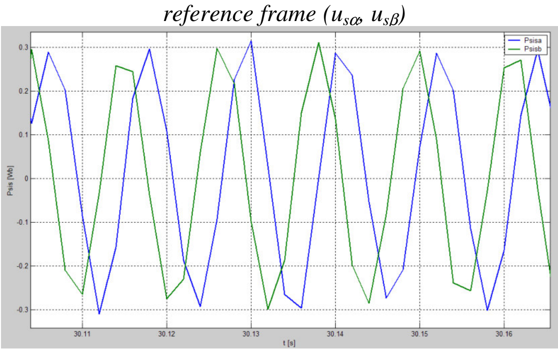

Fig. 11. Estimated stator flux – components of stator flux vector in stationary reference frame ($\Psi_{s\alpha}$, $\Psi_{s\beta}$)

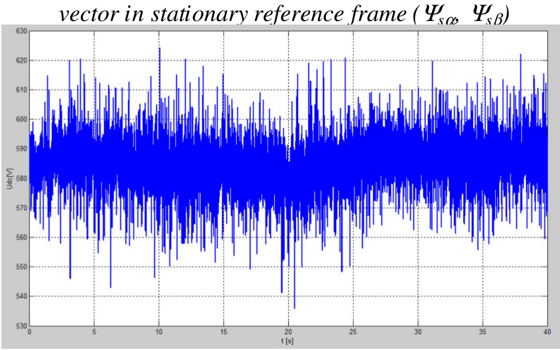

Fig. 12. Converter dc-link voltage

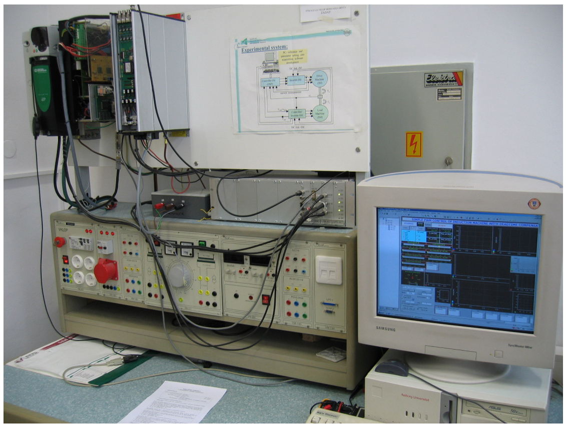

Fig. 12. Experimental workplace

4. CONCLUSION

This contribution uses sliding mode theory for design of robust sensorless control of the induction machine drive with DTFC. This contribution describes proposed drive control and designed flux observer as well as presents simulation results and experimental evidence of the laboratory prototype of the drive. The proposed sensorless control is able to operate the drive close to the zero speed (the prototype has been successfully tested down to 5 rpm). The proposed control system is only slightly dependent on the system parameters changes.

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